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Electrical Energy Storage Projects, Applications & Research Challenges for Grid Support: Description of Recent SNL Projects

Daniel Borneo, P.E.

Presentation for

EMA Energy Storage Workshop

Singapore

August 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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SAND Number 2015-6281C

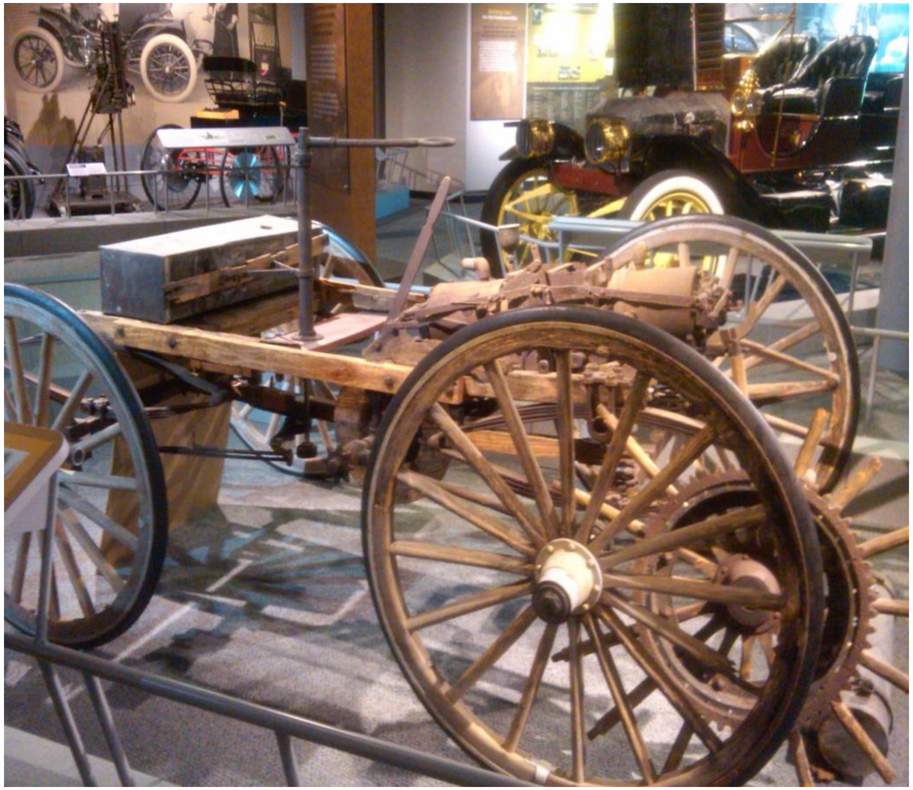
AGENDA –

Presentation Outline

- Sandia's Energy Storage Program
- Energy Storage Industry
  - Grid Problems Mitigated by Energy Storage
  - Projects and Applications
  - Summary – Challenges and Gaps

Innovation:

Something to Consider



One of the first gasoline powered cars ~1891 by Henry Nadig of Allentown, Pa.

Courtesy of American Automobile Museum, Allentown, Pa.

Courtesy of American Automobile Museum, Allentown, Pa.

Innovation: Something to Consider

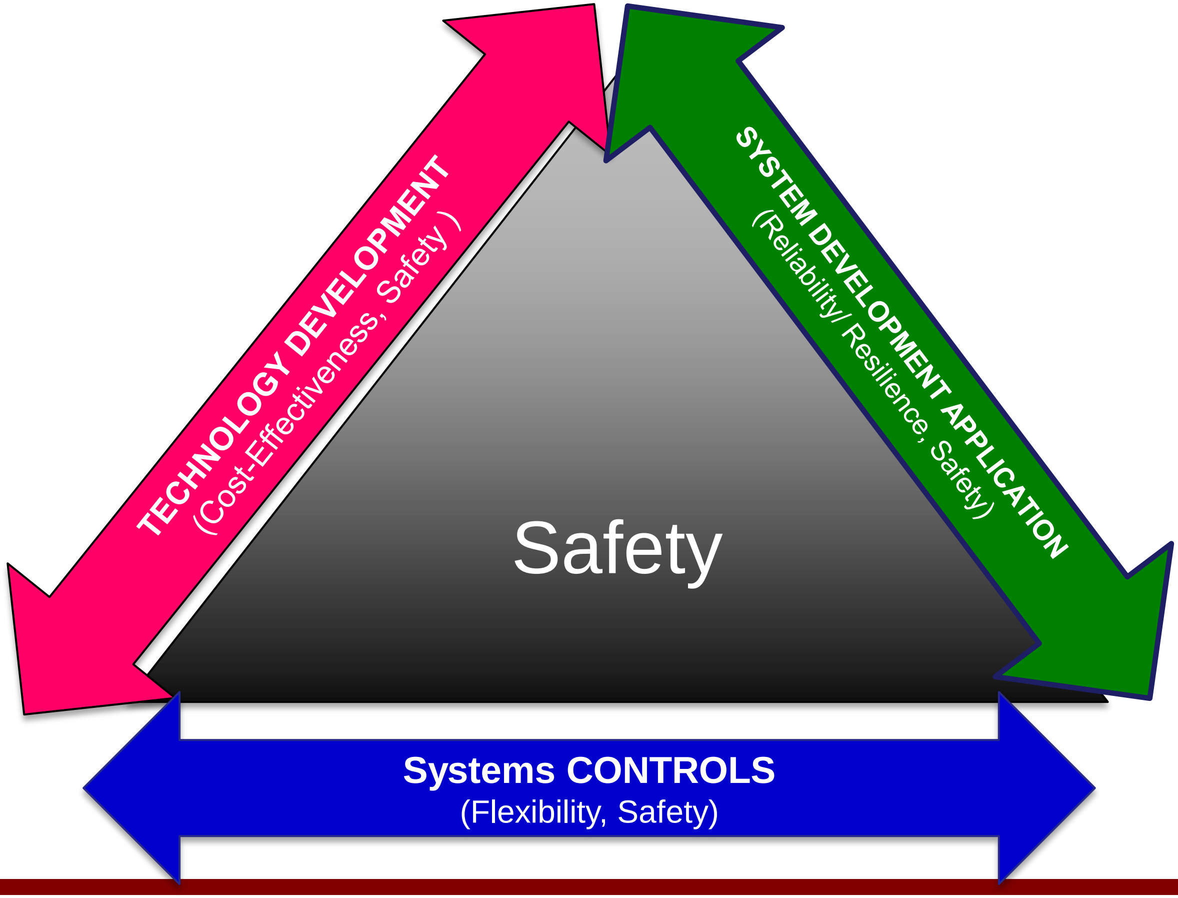
*Quotes about the Nadig in 1891**

- Blasted as a "**dangerous device**" – backfiring caused **FIRES!**
- Car **not allowed** on the **streets** during the day as it **"frightened"** the horses
- Constable served notice; drivers/operators could be **arrested,** held liable for creating a "**public nuisance**"
- "Shouts of 'Get a horse!' were followed by the grand insult of the day - "***Flying Cabbages***" that were thrown at the hapless Nadig."

** Whelan, Frank "Did Auto Age First Dawn in the Valley? Allentown Mechanic Built One of Country's First Gas-powered Cars" Sept, 14, 1989 The Morning Call*

DOE/Sandia's Energy Storage Mission

DOE Office of Electricity (OE) drives **electric grid modernization for the nation's energy infrastructure, and** Sandia National Laboratories (SNL) manages the majority of OE's Stationary Energy Storage program. SNL accomplishes this mission through **R&D**, **applied engineering, analysis**, **testing & demonstrations** and by partnering with Industry and academia.



Sandia's ES Program

Energy storage is an enabling technology that:

1. Improves grid *efficiency*
2. Improves grid *reliability and resilience*

DOE - Identified Key Challenges:

1. Lifetime return on investment (**cost** / **performance**)
2. Validated **Reliability** and **Safety**
3. **Regulatory** environment
4. **Market** acceptance

Five Sandia Thrust Areas to Meet Grid Challenges

U.S. DEPARTMENT OF ENERGY | Sandia National Laboratories

Nanoscopic

- **Materials and Systems Development**
  - Leading the **development** of next-generation technologies
  - Improving current **technology** (flow batteries, flywheels, etc.)
- **Power Electronics**
  - **Developing** and testing new wide-bandgap power-electronic devices
- **Energy Storage Systems Demonstrations and Testing**
  - Laboratory **testing and analysis** from individual cells to 1MW systems
  - **Field** deployments
  - State-Initiated Demonstration Project Development
- **Grid Analytics and Policy**
  - Providing **assessments** of the impact of storage placement
- **Outreach -** Leading publications and meetings to **help** educate the Grid Energy community

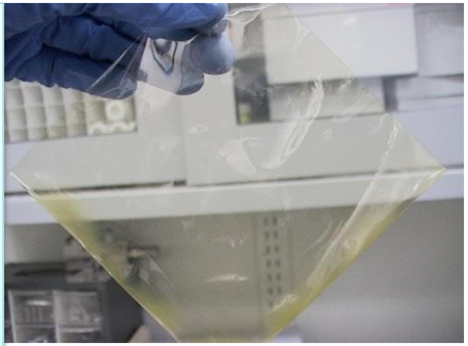
Macroscopic

Materials and Systems R&D

Goal - Improve the cost, performance and reliability of energy storage systems.

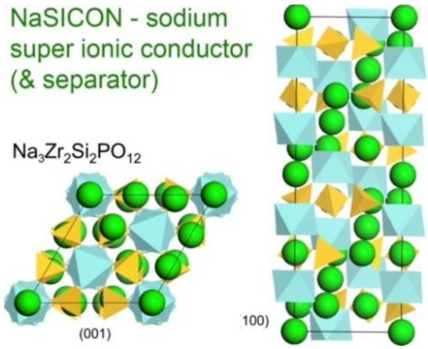
Near term – *Improvement* of existing energy storage technologies:

- Flow Batteries (separators, electrolytes, etc.)
- Flywheels (Carbon composites, new lift magnets)
- New Capacitor materials



New low-cost flow battery separator materials

NaSICON - sodium super ionic conductor (& separator)



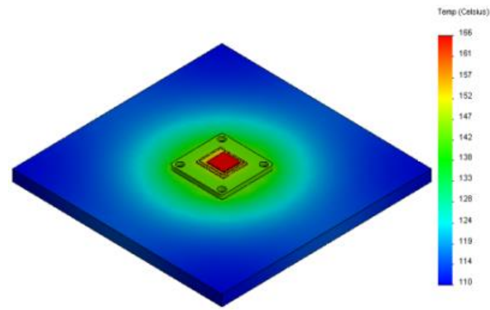
Longer term – *Revolutionary* new energy storage systems:

- Nitrogen - air batteries (high energy density)
- Sodium-iodide batteries (low cost)

Power Electronics

Goal - Use of wide bandgap semiconductor devices, advanced topologies, and controls significantly reduce installed cost and footprint, improve control capability, and increase reliability of ES devices and equipment.

P_{dis} = 200 W, Max Temperature = 166 ° C



Arkansas Power Electronics International
15kV Discrete SiC Package

Recent Recognition

- Four R&D100 Awards
- Three U.S. Patents
- Over 40 technical publications
- Dr. Stan Atcitty received Presidential Early Career Award for Scientists and Engineers

Demonstrations and Testing

Goal - Assist the ES industry in determining how to maximize return on investment (ROI). These projects help to ensure ROI and facilitate adoption via improving confidence in safety, reliability, system performance and cost-effectiveness.

Two Pronged Approach

Energy Storage Test Pad (ESTP) – 1MW test pad at SNL used to test and evaluate the safety, reliability and performance of ES systems.

Battery Test Lab – Battery cell and module testing for safety and performance.

Field Demonstrations - Assist in the selection, installation, optimization and performance analysis of ES systems while providing verified technical and economic evaluations of technologies.

CESA-ESTAP Program – Work with State Energy Offices to advance the use of Energy Storage though state-led initiatives.

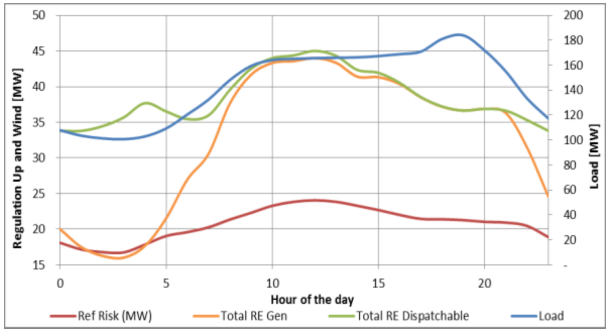
SNL Industry Collaborations

Beacon Power	• SNL partnering with Beacon Power on advanced flywheel and magnetic materials.
SunEdison	• Committed $224K for a 24 month collaboration with SNL to demonstrate laboratory-scale prototype of SNL ionic liquid flow batteries.
Arkansas Power Electronics International	• Phase I SBIR project to design and demonstrated a high voltage discrete package capable of housing a 15 kV silicon carbide device.
Southern Company	• A production cost model of the business case for additional bulk electric energy storage in the Southern Company service territory for 2020.
Green Mountain Power, Vermont Dept. Of Energy	• SNL partnering with the state of Vermont and GMP to install a 2MW/3.4MWh ES system with 2MW PV.
Hawaiian Electric Company / Maui Electric Company (HECO/MECO)	SAND production cost model report, entitled "Maui Energy Storage Study," released in December 2012.
Connecticut, Massachusetts, New York, New Jersey, Maryland, Vermont	• SNL partnering with various state energy departments to develop projects and provide technical consulting.
Aquion Energy, SustainX, SEEO, EnerVault, Primus Power.	• ARRA program to develop, test and deploy an ES systems.
Kodiak Electric Association (KEA)	• Project undertaken to maximize the benefit of a 9MW wind system and 3MW ES at Kodiak Electric Association.
DoD	• Support testing of BCIL systems at ESTP - Three out of five systems have been tested.
Duke Energy, Fiamm	• DUKE in collaboration with DOE/SNL is working to further research in optimizing energy storage for utility grid applications.
PNM, NEDO, MDS, East Penn	• Verify the benefit of combined ES / PV at PNM's Prosperity site.
CPUC, SunPower/DNV-KEMA/UCSD, ICE	• Sunpower Corp under a grant from the California Public Utility Commission (CPUC) engaged in work to demonstrate an ES / PV system with SNL's assistance..

SNL University Collaborations

Colorado School of Mines **University of Maryland**	• Scale-up and production of SNL ceramic; active in supplying the engineered ceramic in the format necessary for use in the battery.
Oregon State University	• Co-developing ultra-capacitors with SNL; OSU is focused on the roll of defects in the SNL material.
Iowa State University	• Collaboration with SNL to compare and contrast how reserve markets are structured in the (seven) wholesale power markets in the U.S.
University of California **San Diego**	• SNL/UCSD collaboration to develop and deploy MW-scale energy storage system on the UCSD campus.
Case Western Reserve University	• SNL-managed, university-guided project researching the negative electrode materials.
The State University of New York	• SNL-managed university-directed project to develop synthesis pathways for cathode oxides.
Arizona State University **Iowa State University**	• SNL-managed, university-led project to demonstrate composite non-brittle solid electrolytes.
University of California/Los Angeles; Drexel University	• SNL-managed, joint-university project to test prototype devices with integrated mesoporous electrode architectures.
Texas Tech University	Partnering with University and others to evaluate ES in a wind application.

Grid Analytics and Policy



Motivation

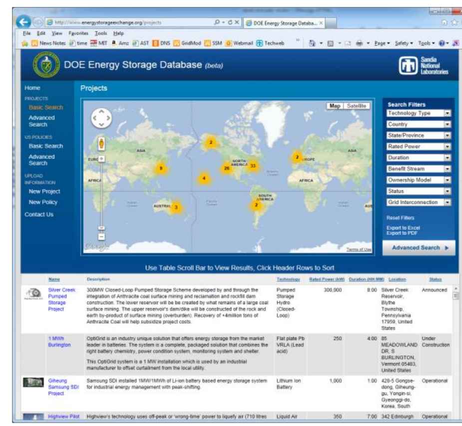
- Determine where and how to implement storage with the greatest benefits to the utilities, regulators and consumers (e.g., grid resilience, frequency regulation, peak shifting)
- Explore grid-level storage cost effectiveness in actual markets:
  - Evaluate impact to the delivered cost of electricity, especially with *projected increases in renewable deployment;*
  - Study pumped-storage hydro, flywheels, and batteries as well as combinations of these options.

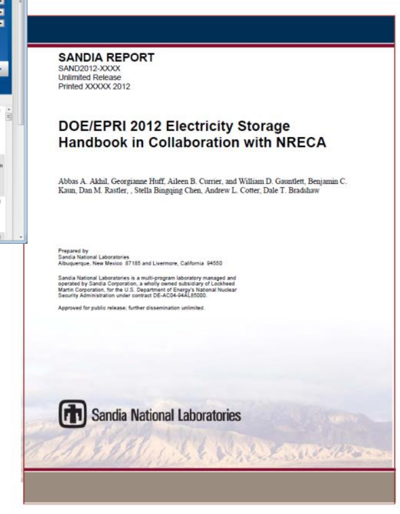
Recent Accomplishments

- Published 5 reports – two on a new wholesale market design, and three storage valuation studies (on Maui, NV Energy, and Southern Company).
  - Maui study provided additional evidence that storage ameliorates wind curtailment and is an economic option
  - NV Energy study showed that new storage deployments can be cost effective when pay-for-performance is enacted.

Outreach

- **Electrical Energy Storage Applications and Technologies Conference (EESAT)**
  - This international conference presents the latest advances in storage technologies, analytic and economic methods and demonstrations
- **DOE Online Energy Storage Database**
  - This tool disseminates project information on active energy storage projects worldwide. energystorageexchange.org
- **Handbook**
  - A resource that provides a comprehensive guide for energy storage: It details the current state of commercially available energy storage technologies. The manual matches applications to technologies and offers information on sizing, siting, interconnection issues and cost matter. sandia.gov/ess/publications/SAND2013-5131.pdf

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DOE/EPRI 2012 Electricity Storage Handbook in Collaboration with NRECA

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What Problems Can ES Help Alleviate?

Electrical Energy Storage Overview

- Electrical energy storage decouples generation from demand:
  - Adds **reliability** to the nation's electricity power grid
    - The lights are on when you flip the switch, even in an emergency
- Electrical energy storage makes **renewable energy resources more dispatchable**
- Electrical energy storage can support an **aging** or **overloaded** grid
- Energy storage faces unique *technical and market* **challenges**:
    - Nascent industry
    - Reliability of systems
    - Cost of systems
    - Regulatory polices

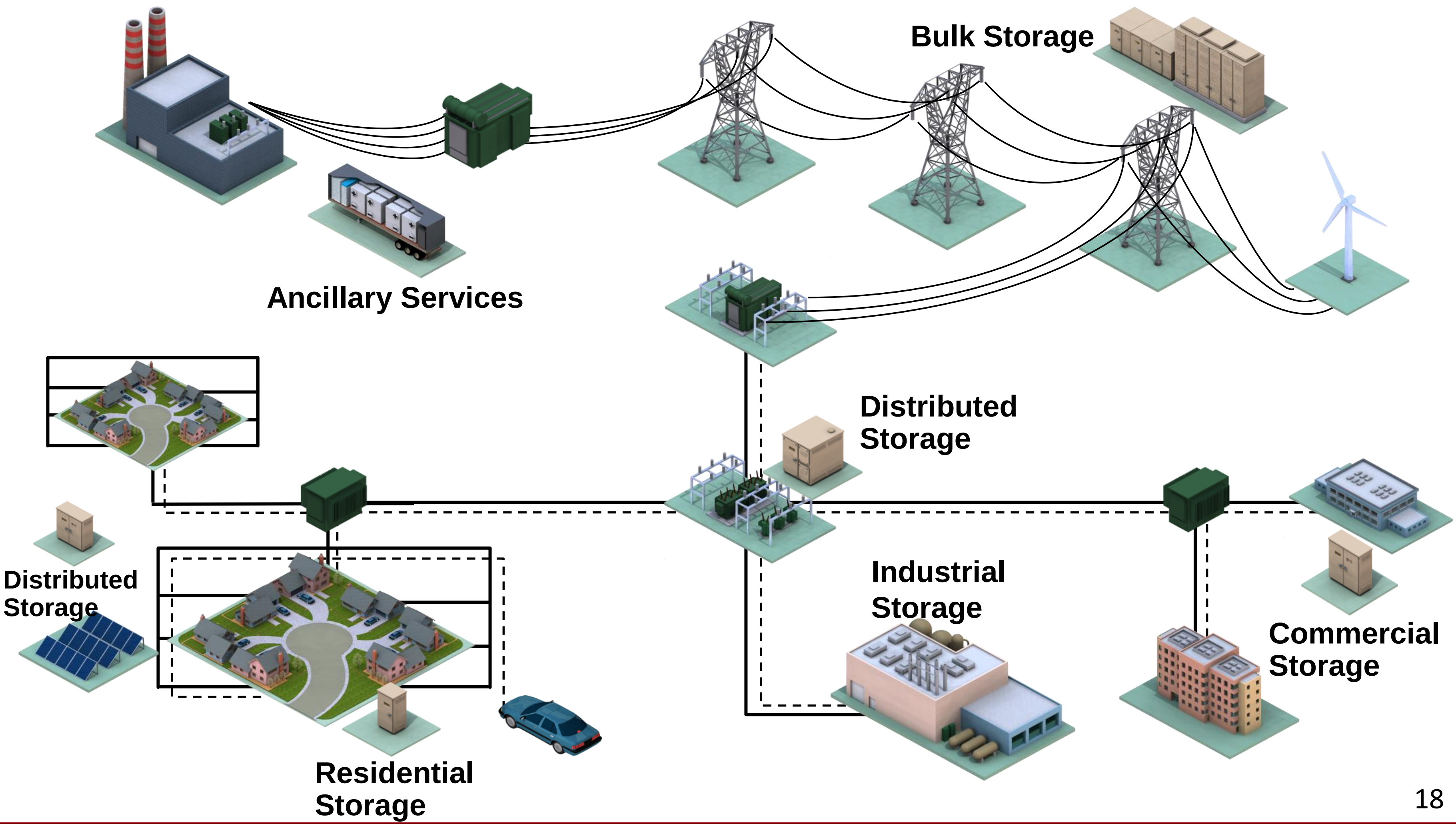
Energy Storage Applications

POWER (<15min) **ENERGY** (>1hr)

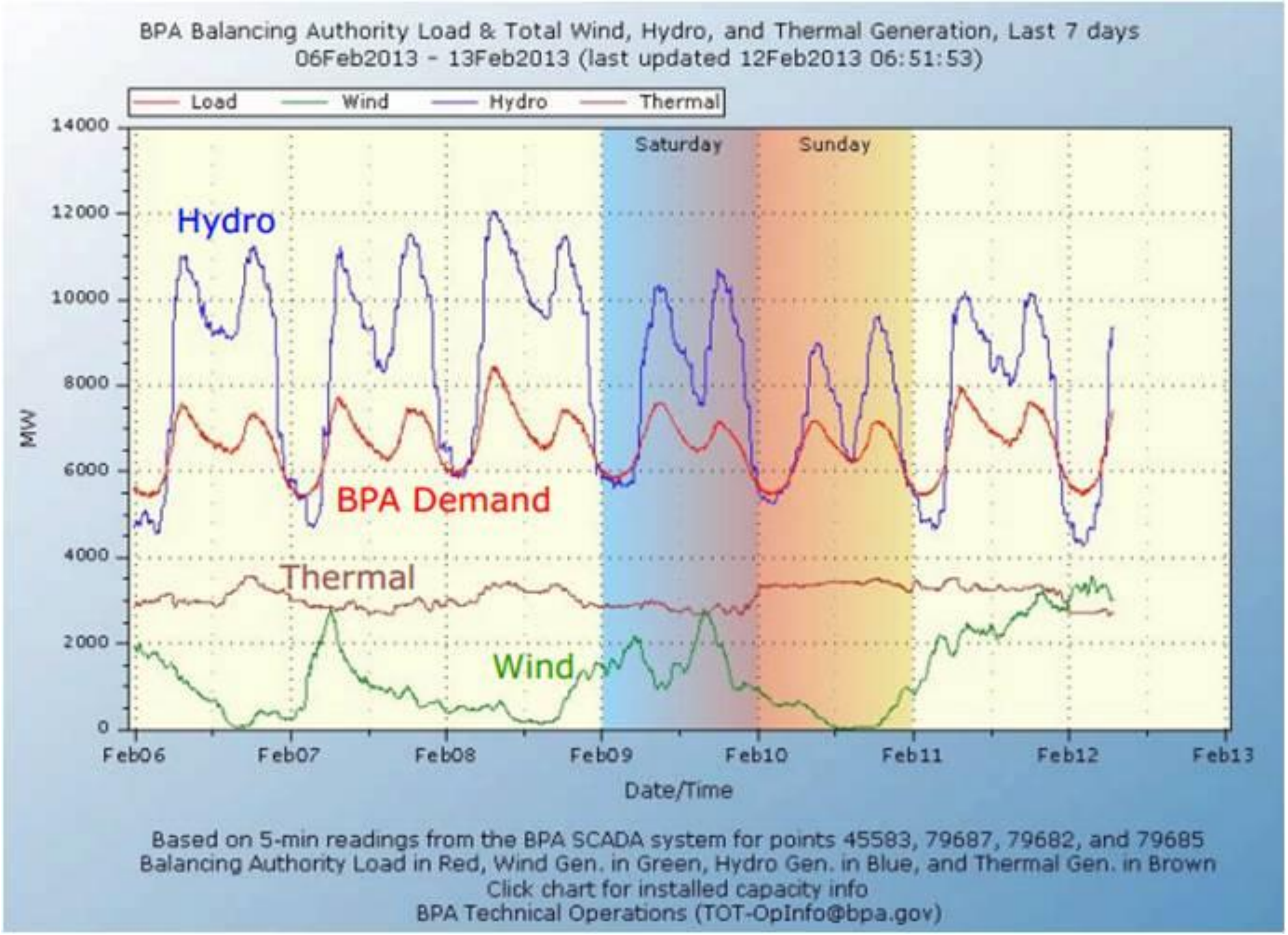
	seconds	minutes	hours
LOAD	**PQ, Digital Reliability, UPS**	**Spinning Reserve/ Load Following, UPS**	**Peak Shaving, Load Shifting**
GRID	**Voltage Support, Transients, Regulation**	**Dispatchability for Renewable Energy Resources**	**T&D Congestion Mitigation, Time of Use Arbitrage, Upgrade Deferral**

Role of Electrical Energy Storage on the Electricity Grid

Resource: ESA Basics of Energy Storage Workshop 2011/ SNL-EPRI

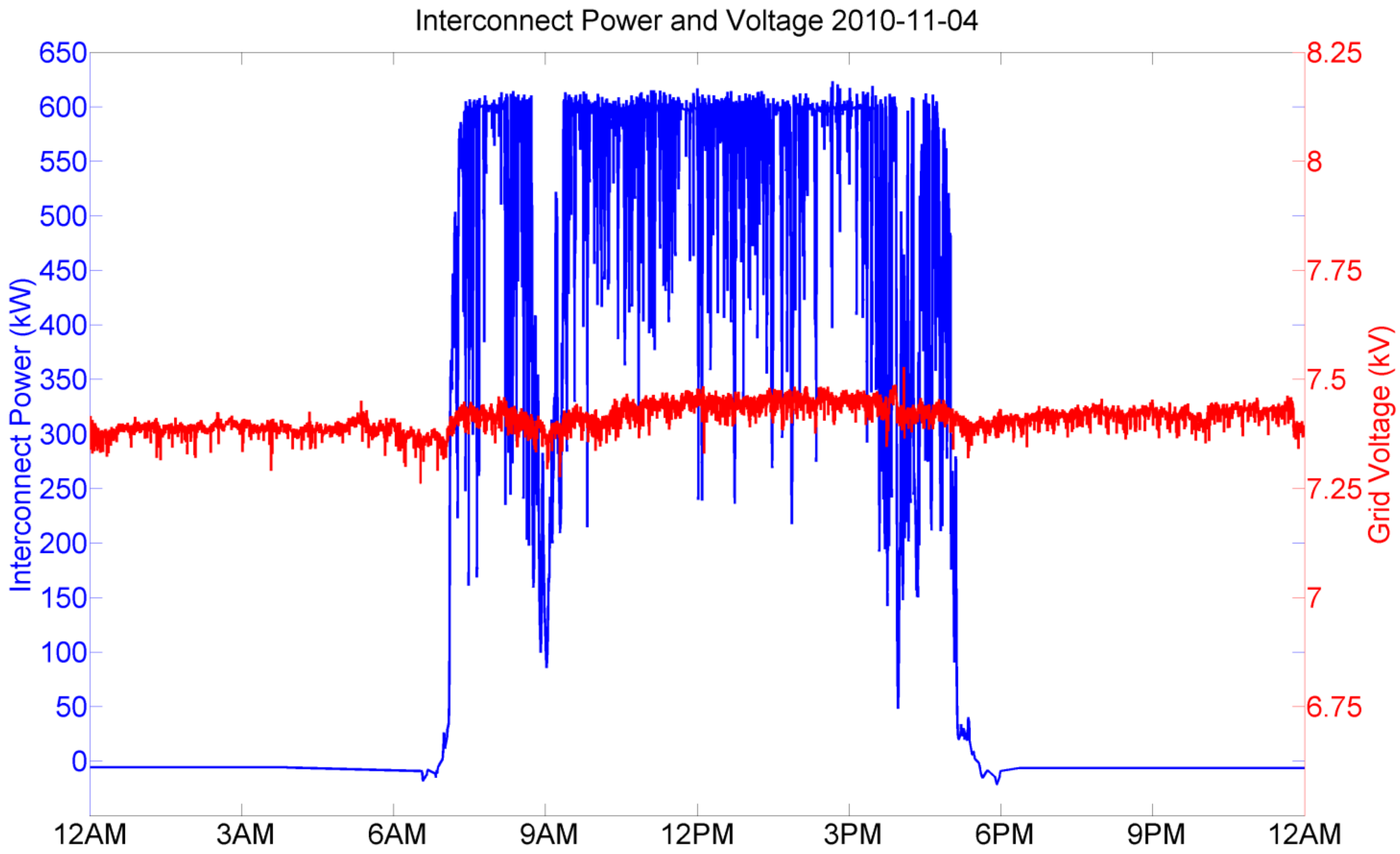


BPA Generation and Load Profile



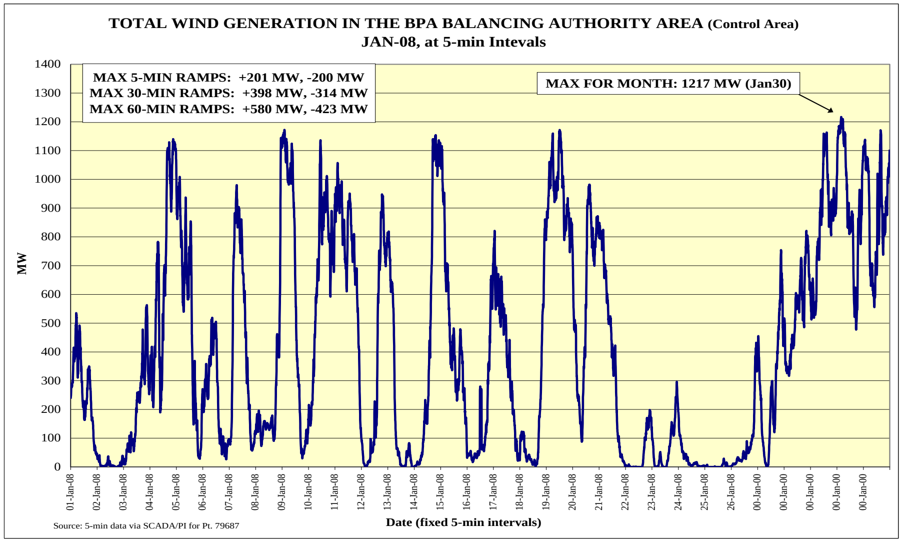
Lanai- PV

Power and Voltage



Variable Energy Resources Create More Demand for Balancing

Wind

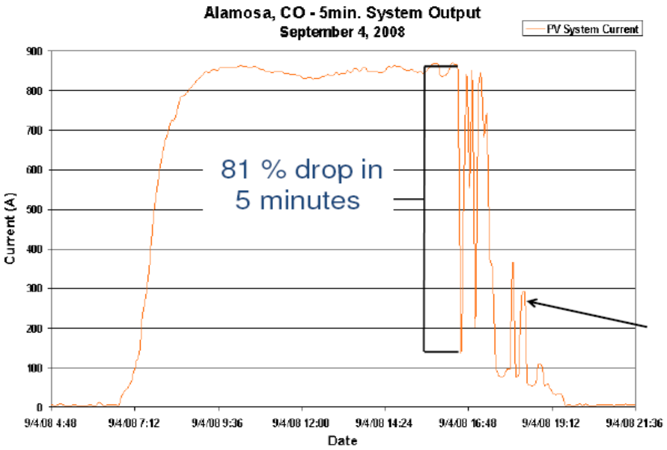


Bonneville Power: Wind data for one month

- Power range >1200 MW
- Fluctuations for 5 minute and 6 hour time frames

Solar

Solar energy sources are highly variable



Output from an 8MW solar PV panel in Colorado on 9/4/08

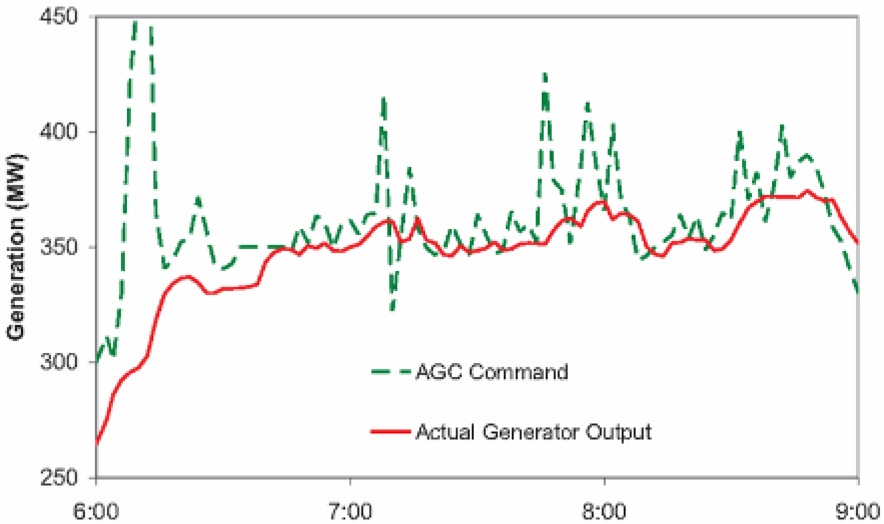
High variability due to clouds

Typical daily solar power output pattern

- Fluctuations can be >80% rated power in 5 minutes
- Can continuously fluctuate on partially cloudy days

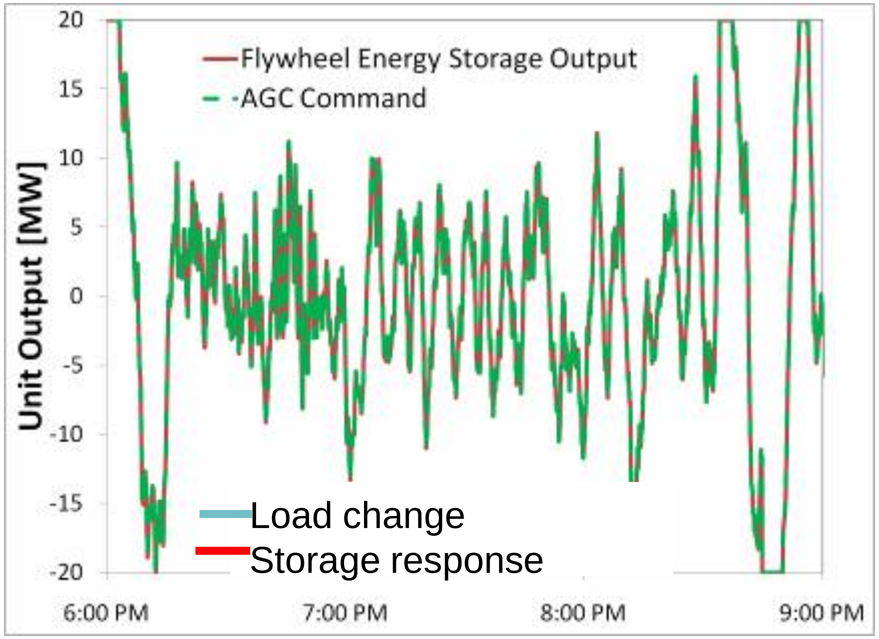
Renewables need all three time scales of storage

Fast Response: Speed Matters



Significance of ES Contribution

Generators are slower than load changes

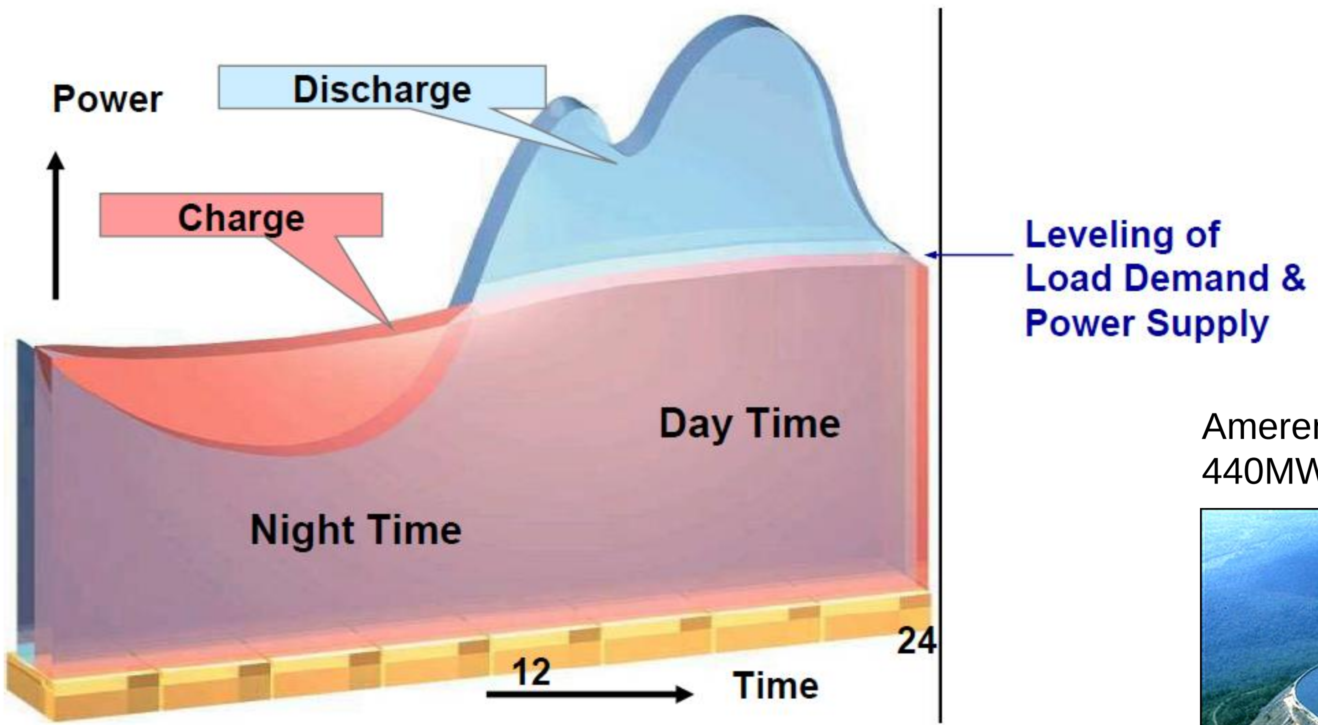


ES Attributes

- Storage has a near instantaneous response
- It only needs enough for gen to catch up
- Works with slower, more efficient generators
- Helps firm variable generation like wind & solar

Storage for Load/Power balancing is new state of the art

Storage Applications – Load Leveling

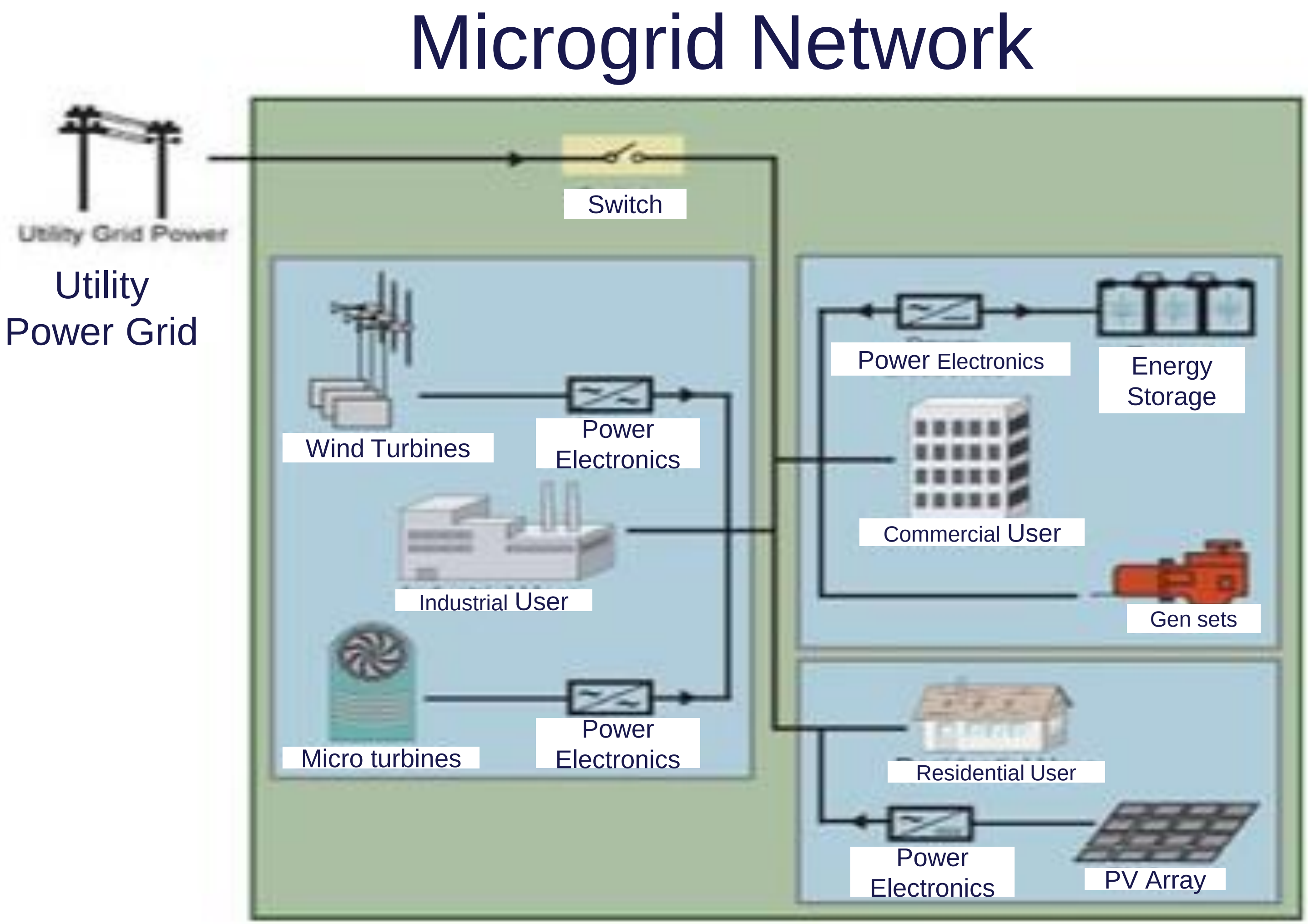


Ameren: Taum Sauk, Missouri
440MW re-commissioned May, 2010

Arbitrage has difficult economics today

Microgrid Applications –

i.e. Disconnected Distribution Line



NY Revisited – 2012 Super Storm Sandy
Natural Disasters, Power Outages, & ES

The New York Times

N.Y. / Region

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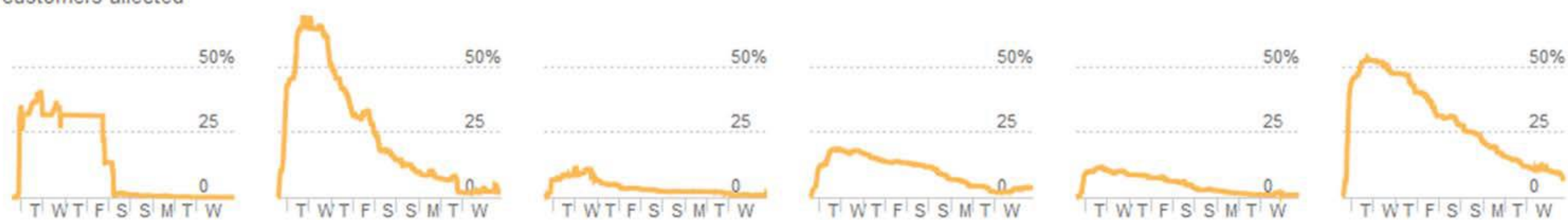
UPDATED October 30, 2012

FACEBOOK TWITTER GOOGLE+ E-MAIL SHARE

A Close Look at Power Failures in New York City 5:45 P.M. ET Nov. 8

Hurricane Sandy knocked out power to hundreds of thousands of people in the area. Data updated every 15 minutes.

Manhattan 792 customers affected | **Staten Island** 3,435 | **Brooklyn** 7,912 | **Queens** 21,235 | **Bronx** 3,168 | **Westchester** 23,607



Major outages can last for 5-7 days in some disasters; but backup systems are not commonly designed for that type of duration.

Is Storage Expensive?

(The Ugly Truth)

$/kW?	$/kWh?
What is in the “kW”	**What is in the “kWh”?**
Total System Cost?	Environmental conditions?
Life Cycle Cost?	System losses?
Balance of Plant Cost?	KWh Stored?
Installation Cost?	KWh Delivered?
Replacement Cost?	Number of cycles?
Disposal Cost?	Cost of operations?
	Maintenance Cost?

Cost metric must include a variety of important elements.

Several Available

Storage Varieties/Options

Decreasing cost per kWh

Type	Storage Mechanism	Common Duration	Cycles
Capacitor	Electrical charge	Seconds (minutes)	100,000’s
Flywheel	Kinetic energy	Seconds / Minutes	1000’s - 100,000’s
Battery	Electro-chemical	Minutes (hours)	100’s-1000’s
Pumped Hydro	Potential energy	Hours	1000’s
Thermal	Ice, Molten Salts	Hours	1000’s

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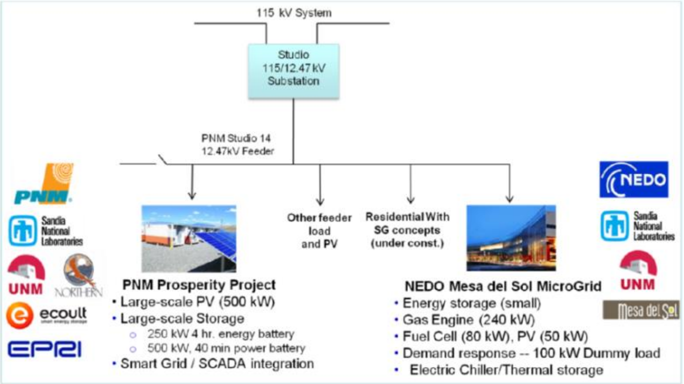
World-Wide Energy Storage Projects

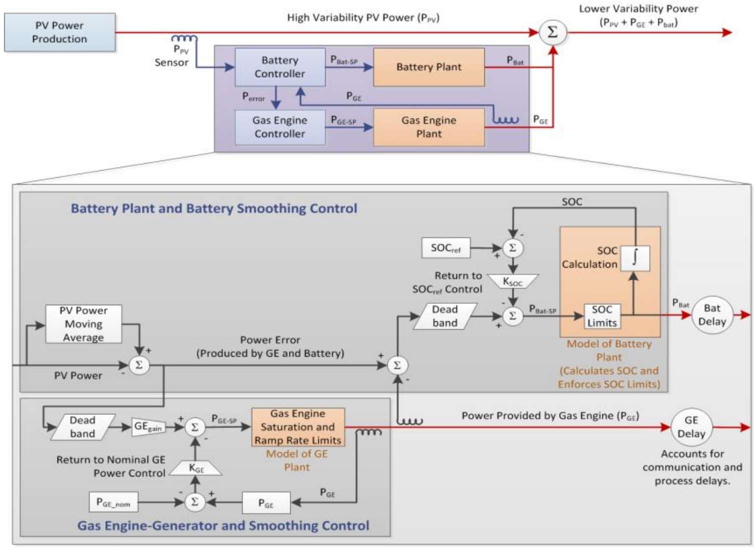
What's happening in the Industry -

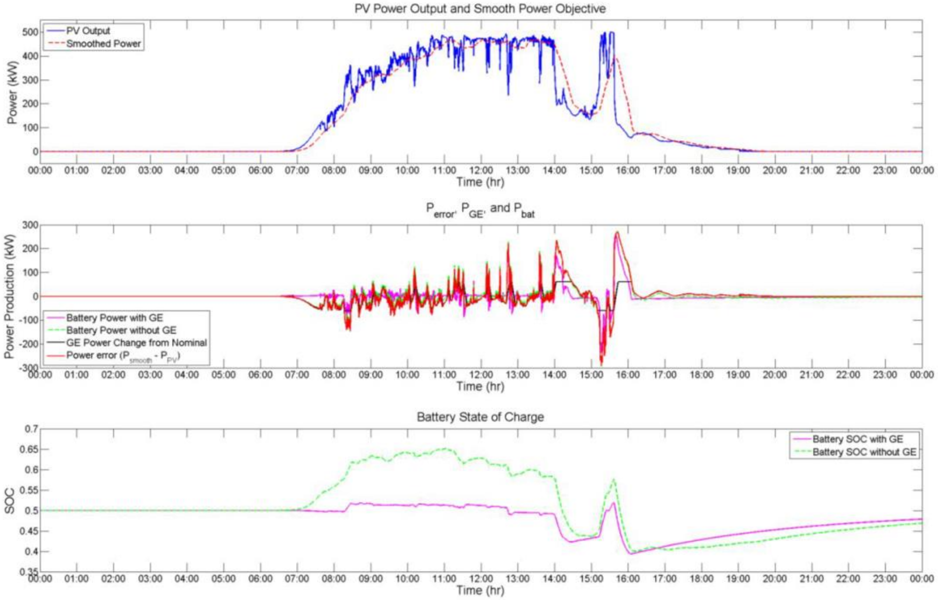
(www.energystorageexchange.org)

Mesa del Sol PV Output Smoothing Demonstration Project

- Goal: Smooth 500 kW PV output with distributed resources (i.e., natural gas gen set, battery, and fuel cell)
  - Sandia has optimized a PV smoothing control algorithm to minimize power output variability and battery use.
  - Field demonstration began in the summer of 2013.

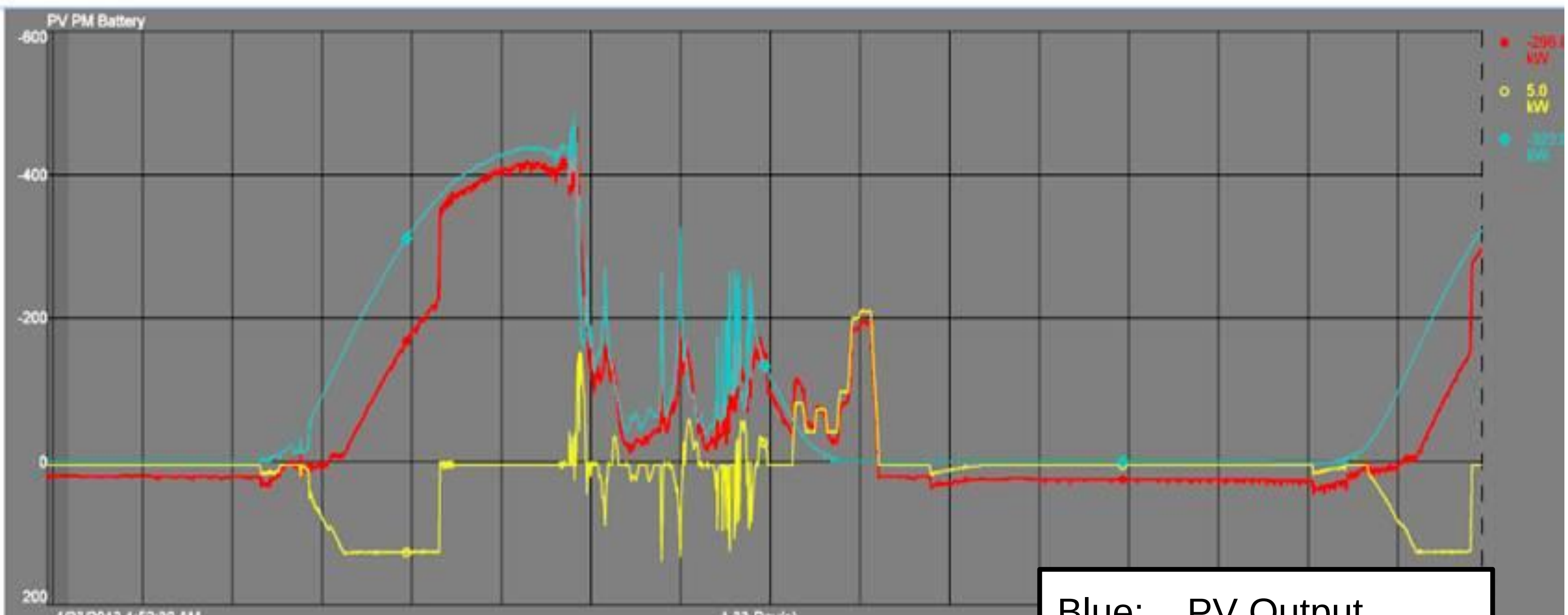






PNM Prosperity Project

Evening Peak Shaving & Simultaneous Smoothing



Blue: PV Output
Yellow: Battery Output
Red: Primary Meter

NEDO/ LOS ALAMOS New Mexico

Smart Grid Demonstration Project

New Energy and Industrial Technology Development Organization (NEDO) has commissioned a Demonstration Project in Los Alamos County, New Mexico (USA):

- 800 kW/1-hr Lead Acid Battery (VRLA)
- 500-kVA PCS for storage batteries.
  Two circuits of DC/DC converters that can be connected to storage batteries and photovoltaic cells.

Demonstration of suppressing short-term output fluctuations in photovoltaic power generation through the charging and discharging of lead-acid batteries. More information at:

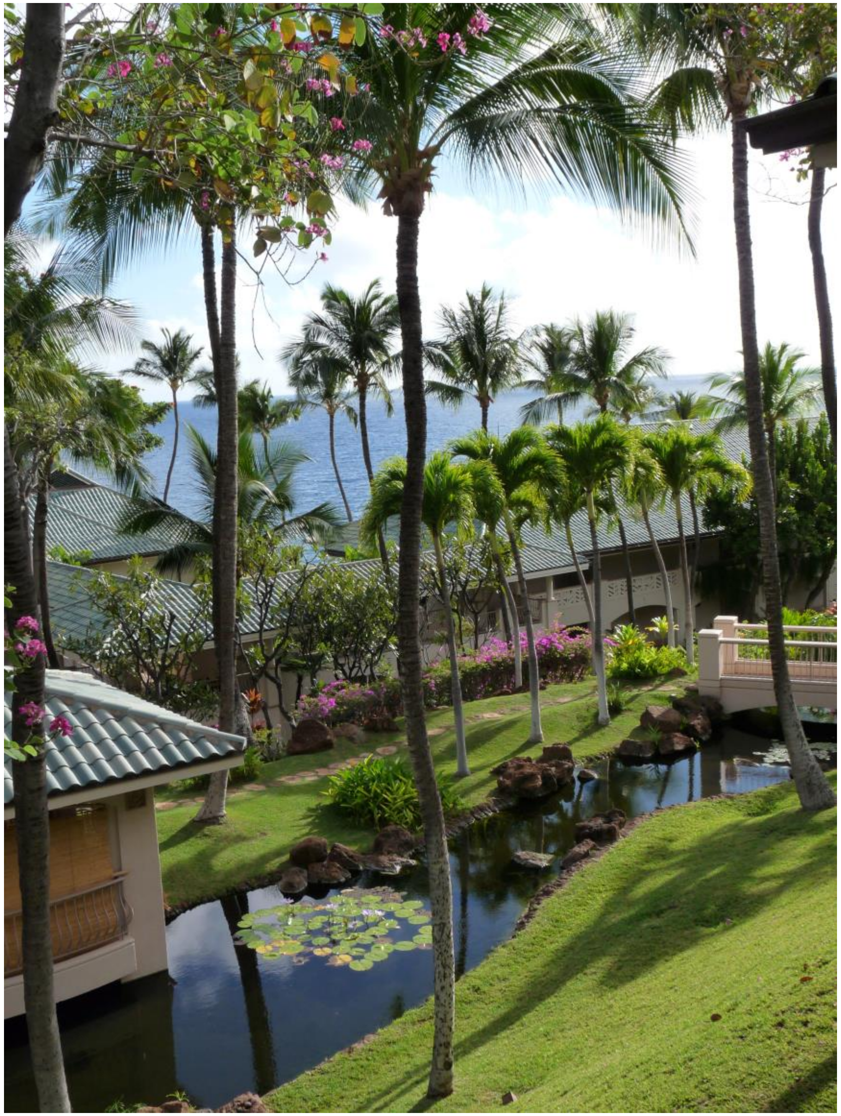
http://www.hitachi.com/New/cnews/1209...

Lanai- PV & Micro grid

BACKGROUND INFO

- 1.2-MW photovoltaic (PV) power plant in Lanai, Hawaii
- Operating since December 2009

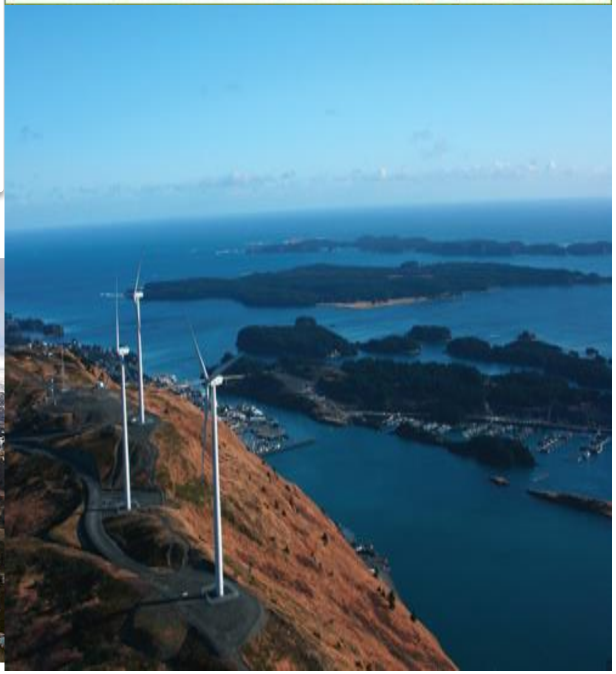
  on a 5 MW grid
- An interconnection study concluded that PV output ramps had the potential to negatively impact system frequency.
- System output curtailed to 50%



- In 2011, a 1.5MW 40 min energy storage system was installed and allowed the PV system to operate at rated output.

Kodiak -System Modeling & Simulation

Project Objective: Enhance system frequency and voltage stability.



BACKGROUND

Kodiak Electric Association, Inc. (KEA) is a rural electric cooperative located in Kodiak, Alaska.

Generation comes from a mix of hydroelectric turbines, diesel generators and wind turbines.

An XP 3MW 0.25h LA ESS was installed to mitigate the variability of the 9MW wind system.

Laurel Mountain Energy Storage Project

- The 32 MW /0.25hr Li-ion ES system is a fully-integrated portion of the Laurel Mountain Wind Farm.
- Developed by AES Wind.
- Provides frequency regulation in the PJM market and ramp rate control for wind variability.
- Operational Q3 of 2011.

Location
Belington, West Virginia (PJM)

With 150 MW of resources online, AES Energy Storage operates the largest fleet of battery-based storage assets in commercial operation today.

SMUD -High Penetration Solar Portal

Sacramento Municipal Utility District (SMUD) piloted both residential energy storage (RES) units and community energy storage (CES) systems in Anatolia. Thus far, the research team has installed 15 RES units in the garages of volunteers.

In February 2012, the team planned to set up three additional CES systems in the neighborhood with each CES connected to the pad-mounted transformers on distribution feeders – all sized to work with the group of homes serviced by each transformer. These are about three times larger than the residential units, but can be shared between five to ten homes.

SMUD pioneered this technology as part of the Photovoltaic (PV) and Smart Grid Pilot project, which was funded by the SunShot Initiative of the U.S. Department of Energy (DOE), the American Recovery and Reinvestment Act of 2009 (ARRA), and industry partners. The utility company also planned to develop two-way communication capabilities and analyzing production characteristics of distributed PV systems (with a $5.96 million award; $4.3 million from DOE and $1.66 million from SMUD and partners).

Grid-Connected, Long Duration Energy Storage EnerVault

Fe-Cr Redox Flow Battery 1 MW-hr_{AC}

- DOE ARRA Storage and CEC funding
- Began commissioning January 2014
- Co-located with a PV solar system driving water pumping at an almond farm in Turlock, CA

Largest Iron-Chromium Redox Flow Battery Installed Globally

- EnerVault - 250 kW_{AC}, 4-hour Iron Chrome
- Inherently safe system design based on NASA science
- Grid-scale EnerVault systems advertised to meet DOE cost targets and deliver 4-12 hrs of energy

EaglePicher Demonstration

Joplin, Missouri

EP POWERPYRAMID™ INSTALLATION,
Project Commissioned June 2012

- EPT's PowerPyramid™ hybrid energy storage
  - 1 MW/2 hr ES
  - Consists of three systems:
    - Li-ion, tubular Pb-Acid and AGM Pb-Acid
  - Peak Shaving and UPS

View real-time operational statistics and monitoring at: www.eptpowerpyramid.com

- Multiple energy inputs and storage tiers housed in 4 - 40 foot containers
  - Tier #1 provides rapid response to short duration load changes and high cycle count
  - Tier #2 can provide medium-duration load support for longer duration load fluctuation and medium cycle count
  - Tier #3 can provide long-duration load support for extended load fluctuations and low cycle count

Closing Technical & Economic Gaps: Key ES Challenging Questions

- How do we design and correctly size Energy Storage Systems?

- How do we utilize and control ES so the system performs multiple functions to get the most value for the least cost?

- ES is like a life insurance policy: **term life** - no value until a disaster hits; or **whole life** – you can utilize the assets (for a price). What capability can be built into an ESS to access the service during normal operation and in emergency? How do you monetize that capability?

Safety & Reliability Resource In Development:

Battery and System Testing Website

For more information, visit the website at:
www.sandia.gov/batterytesting

2015 Call:
Oct 5 – Oct 25, 2015.

The database will be open for *FAST-Track* Proposals. These should be limited in scope and have strong justification for expedited processing.

Contact: Summer Ferreira
srferre@sandia.gov
or David Rosewater
dmrose@sandia.gov

Resources

- www.cleanenergystates.org/projects/energy-storage-technology-advancement-partnership/
- www.eelectricitystorage.org
- http://energy.gov/oe/services/electricity-advisory-committee-eac

On behalf of the entire workshop team, we would like to thank you for your attention as well as to express gratitude to our SNL sponsor at the U.S. Department of Energy (US DOE) Office of Electricity (DOE/OE),

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Questions?

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